

*HUMAN SIGNAL-DETECTION PERFORMANCE:  
EFFECTS OF SIGNAL PRESENTATION PROBABILITIES  
AND REINFORCER DISTRIBUTIONS*

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University students participated in one of four standard two-choice signal-detection experiments in which signal presentation probability was varied and the reinforcement distribution was held constant and equal. In Experiments 1, 3 and 4, subjects' performance showed a systematic response bias for reporting the stimulus presented least often. Experiments 1 and 4 showed that this effect was reliable with extended training and monetary, rather than point, reinforcement. In Experiment 2, all correct responses were signaled in some way, and this produced the opposite relationship between signal presentation probability and response bias. Experiments 1 and 3 found that explicitly deducting money (intended as punishment) for equal numbers of incorrect responses on each alternative, or varying the obtained overall rate of reinforcement, produced no clear change in response bias. The bias, shown by humans, for reporting the stimulus presented least often remains a challenge for theories of stimulus detection.

*Key words:* signal detection, signal presentation probability, reinforcer distribution, discriminability, response bias, humans

In a typical signal-detection task, the subject is presented with one of two stimuli on each trial ( $S_1$  or  $S_2$ ). The two stimuli usually vary along some physical dimension, such as wavelength (color) or size. Subjects are required to make one response (e.g., a left key press) when  $S_1$  is presented, and a different response (e.g., a right key press) when  $S_2$  is presented. These two responses are labeled  $B_1$  and  $B_2$ , respectively. This leads to four possible outcomes, as shown in Figure 1. The  $B_w$  and  $B_z$  cells of this matrix indicate trials on which subjects make correct discriminations between the two stimuli. The  $B_x$  and  $B_y$  cells in the matrix indicate incorrect responses. Usually, subjects receive some sort of reinforcement or feedback (i.e., money, points, or "correct") for their correct responses. Signal-detection theory attempts to describe choice behavior ( $B_1$  or  $B_2$  responses) as a function of two independent processes. First, it attempts to measure subjects' ability to discriminate between stimuli (i.e., their tendency to respond  $B_1$  when  $S_1$  is presented and  $B_2$  when  $S_2$  is presented independent of rein-

forcement and other factors). Second, it provides a means to measure their response bias (i.e., any tendency to favor one response over another, irrespective of the stimulus presented).

Davison and Tustin (1978) developed a behavioral model of signal detection that described signal-detection performance in terms of how stimulus disparity and the consequences for responding influenced subjects' response allocation. Davison and Tustin provide a full account of this model, but only the measures of discriminability and bias derived from this model are relevant here. Discriminability is measured by half the log (base 10) of correct responses ( $B_w$  and  $B_z$ ) over incorrect responses ( $B_x$  and  $B_y$ ),

$$\log d = 0.5 \log \left( \frac{B_w B_z}{B_x B_y} \right). \quad (1)$$

This discriminability measure ( $\log d$ ) is comparable to traditional signal-detection measures of discriminability (e.g., Green & Swets, 1966; Luce, 1963) and is intended to remove the effects of response bias due to reinforcer effects and any other systematic biases.

Response bias is measured by the half the log (base 10) of left-key responses ( $B_w$  and  $B_y$ ) over right-key responses ( $B_x$  and  $B_z$ ).

$$\log b = 0.5 \log \left( \frac{B_w B_y}{B_x B_z} \right). \quad (2)$$

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		response	
		B <sub>1</sub>	B <sub>2</sub>
stimulus	S <sub>1</sub>	B <sub>w</sub>	B <sub>x</sub>
	S <sub>2</sub>	B <sub>y</sub>	B <sub>z</sub>

Fig. 1. The four possible outcomes in a typical two-choice detection experiment.

This measure ( $\log b$ ) is comparable to traditional signal-detection measures (e.g.,  $c$  and  $\log \beta$ ) and is intended to cancel out the effects of stimulus discriminability. Unlike traditional signal-detection response bias measures, however, the Davison and Tustin (1978) model stipulates which factors contribute to response bias; that is,

$$0.5 \log \left( \frac{B_w B_y}{B_x B_z} \right) = a \log \left( \frac{R_w}{R_z} \right) + \log c. \quad (3)$$

Here,  $R_w$  and  $R_z$  refer to the overall amount of reinforcers received on each key, and  $a$  represents the sensitivity of the response distribution to the reinforcer ratio. Response bias, in this case, is attributable to the combined effects of the reinforcer distribution [ $a \log(R_w/R_z)$ ] and inherent bias ( $\log c$ ).

The behavioral theory of signal detection makes specific predictions as to which factors effectively bias subjects' performance. Variations in signal presentation probability (SPP), a traditional factor used to produce response bias, do not make theoretical sense within the outcome-driven framework of the behavioral signal-detection model because there is no term to accommodate SPP as an independent factor in Equation 3. Instead, Equation 3 indicates that effective bias manipulations rely on changing the outcomes for choices, such

as relative frequency of reinforcement, rather than changing the SPP.

McCarthy and Davison (1979) compared the efficacy of varying SPP and relative frequency of reinforcement to produce response bias. Two light intensities ( $S_1$  and  $S_2$ ) were presented as the sample stimuli to pigeons in a two-choice recognition paradigm. Left-key pecks resulted in occasional reinforcement when  $S_1$  was presented, and right-key pecks were occasionally reinforced when  $S_2$  was presented. When SPP was varied and the relative frequency of reinforcement was allowed to covary, pigeons' responding was biased toward the key associated with the most frequently presented stimulus (Figure 2, Panel 1). For example, when  $S_1$  was presented on fewer trials than  $S_2$  (negative log SPP values), response bias was negative, indicating a bias toward making  $B_2$  responses, the key associated with the greater frequency of reinforcement. When relative frequency of reinforcement was varied and SPP held constant, again there were response biases toward the key providing the most reinforcement (Figure 2, Panel 2). When SPP was varied and the obtained relative frequency of reinforcement for the two types of correct responses was held constant and equal across the two keys, however, there were no systematic changes in the birds' response biases (Figure 2, Panel 3). Thus, the obtained relative frequency of reinforcement between the alternatives, rather than variations in SPP, controlled response bias. McCarthy and Davison (1979, 1984) contend that SPP has been an effective biaser in past experiments only because the relative frequency of reinforcement typically covaried with SPP (Figure 2, Panel 1). They labeled these types of reinforcement procedures *uncontrolled*. For example, experiments that attempt to manipulate response bias with human performance on a signal-detection task typically vary SPP; but unequal payoffs are also arranged because every correct response is reinforced, or correct responses are intermittently reinforced on variable-ratio (VR) schedules (Stubbs, 1976).

McCarthy and Davison's (1979) examination of Davison and Tustin's (1978) model clarified the role of some of the factors that underlie bias effects. That issue has not often been addressed within traditional approaches to signal-detection theory. Indeed, McCarthy

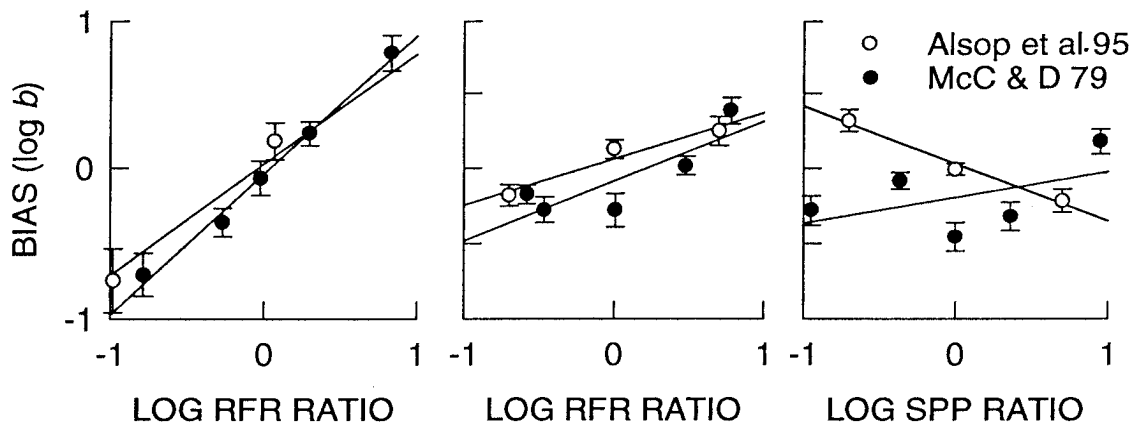


Fig. 2. Panel 1 shows the mean bias (log *b*) for both humans (Alsop et al., 1995) and pigeons (McCarthy & Davison, 1979) plotted against the obtained log reinforcer ratio when SPP was varied and relative frequency of reinforcement was allowed to covary. Panel 2 shows bias when relative frequency of reinforcement was varied and SPP was held constant, and Panel 3 shows bias when SPP was varied and relative frequency of reinforcement was held constant.

and Davison's study remains one of the few that has provided a systematic exploration of sources of bias. The issue has been neglected, probably because signal-detection analyses are typically unconcerned with sources of bias and focus on factors that affect discriminability. However, recent reviews of signal detection have recognized this gap as a shortcoming for developing a comprehensive theory (see Macmillan & Creelman, 1990, 1991). Particularly in short supply are empirical studies that provide a bridge from animal research to human research in the investigation of sources of bias.

In order to address this deficiency, Alsop, Rowley, and Fon (1995) conducted a systematic replication of McCarthy and Davison's study (1979) to determine whether response bias in human subjects is a function of changes in the reinforcement distribution rather than of changes in the SPP. Human subjects participated in six experimental conditions, three in which the difference between the sample stimuli was relatively large (denoted "easy") and three in which the difference between the sample stimuli was relatively small (denoted "hard"). Figure 2 also plots the mean results from Alsop et al.'s easy discriminability conditions in which the level of discriminability shown by the humans was most similar to the level of discriminability shown by McCarthy and Davison's pigeons. When relative frequency of reinforcement

was allowed to covary with SPP, the response bias patterns of the humans and pigeons were similar (see Figure 2, Panel 1). In addition, when relative frequency of reinforcement was varied and SPP was held constant, the responding of both pigeons and humans was biased toward the key associated with the most frequent reinforcement (Figure 2, Panel 2). When SPP was varied and relative frequency of reinforcement was held constant, however, response bias changed in a direction not predicted either by traditional models of signal-detection theory (i.e., bias toward the most frequently presented stimulus) or by behavioral models of signal-detection theory (i.e., no systematic changes in response bias). Instead, the responding of human subjects was biased toward the least frequently presented stimulus (see Figure 2, Panel 3). For example, when the log SPP ratio was negative ( $S_1$  was presented on fewer trials than  $S_2$ ), response bias was positive. Here, responding was biased toward  $B_1$ ; that is, there was a response bias toward the key associated with the least frequently presented stimulus ( $S_1$ ).

The differences found between human and pigeon performance are problematic for research in this area. Alsop et al.'s (1995) finding that human subjects are biased towards the stimulus presented least often is surprising because it is not predicted by either traditional or more contemporary models of signal detection. It also indicates that different

factors might be responsible for producing response bias in human and pigeon subjects. If there is a general species difference in the factors that produce bias in humans and pigeons, then the development of signal-detection models would be made more complicated. An alternative approach to explaining the apparent species difference is to consider the procedural differences between the studies by McCarthy and Davison (1979) and Alsop et al.

There were at least three such differences. The first was the nature of the reinforcer. The pigeons' pecks in McCarthy and Davison's (1979) study were reinforced with food, a tangible consumable item, that was paired with a 3-s presentation of the magazine light. Alsop et al.'s (1995) human subjects received points as reinforcers. The human subjects might have been less sensitive than the pigeons to the reinforcer distribution because the point reinforcers did not hold a value similar to the food reinforcers. (For a discussion of these kinds of issues, see Baron, Perone, & Galizio, 1991; Galizio & Buskist, 1988.)

The second procedural difference involved the consequences for supposedly nonreinforced correct responses and for incorrect responses. Alsop et al. (1995) arranged exactly the same consequences for nonreinforced but correct responses and for incorrect responses; that is, the screen remained blank until the next trial started. In the McCarthy and Davison (1979) study, nonreinforced correct responses produced a 3-s display of the magazine light, and incorrect responses resulted in a 3-s blackout in the chamber. Correct reinforced responses resulted in 3-s access to food, in addition to a 3-s display of the magazine light. It seems likely that the magazine light was a conditioned reinforcer for the pigeons. For example, Williams and Dunn (1991) demonstrated that when a yellow side key was consistently paired with 3-s access to food, the presentation of the yellow side key on nonreinforcement but correct trials facilitated discrimination acquisition. This effect indicated that the conditioned reinforcer (the yellow light) was an effective substitute for the primary reinforcer (access to food). Therefore, although McCarthy and Davison claimed to be controlling the ratio of reinforcers across the keys, an uncontrolled

presentation of a conditioned reinforcer could have been occurring as well. The presentation of the conditioned reinforcer might have not resulted in a shift in response allocation, but it seems reasonable to suggest that this factor produced the differences in performance between pigeons and humans on the signal-detection task.

Third, the amount of training that the human subjects received was less than the pigeons received. Alsop et al.'s (1995) human subjects received 500 trials per condition, whereas McCarthy and Davison's (1979) pigeons received between 4,160 and 11,520 trials per condition. On the one hand, less training is possible when using human subjects because the experimenter can use verbal instructions rather than relying only on direct exposure to the contingencies. On the other hand, the short training time might not have given the human subjects enough contact with the reinforcement distribution to learn that the reinforcement distribution was equal across the keys. If this were the case, the bias shown by humans for responding towards the less frequently presented key might be a transient effect that would disappear with training.

The following experiments were designed to examine whether these procedural differences between McCarthy and Davison's (1979) and Alsop et al.'s (1995) studies contributed to the discrepancy in performance between the pigeons and humans in a signal-detection task. The experiments were also designed to explore the factors that produce the bias, found with human subjects, for reporting the least frequently presented stimulus.

## EXPERIMENT 1

Experiment 1 investigated whether differences in the type of reinforcer given to human and pigeon subjects contributed to the different patterns of response bias found by McCarthy and Davison (1979) and Alsop et al. (1995). In the present experiment, SPP was varied across three conditions, and relative frequency of reinforcement was held constant and equal across the two responses. Instead of receiving 1,000 points for correct responses (Alsop et al., 1995), subjects in the present experiment received a reward with

monetary value; that is, they received 5 cents, and they were paid their total winnings at the conclusion of the experiment. If the discrepancies between the performances of humans and pigeons in this type of task were due to differences in the potency of the reinforcer used for each species (i.e., points vs. food), then human subjects might respond more like pigeons when a more potent reinforcer is used; that is, they might show no systematic preference for the key presented least often when the distribution of money reinforcers is held equal across the two types of responses.

One possible mechanism that could explain bias for the response correlated with the less frequently presented stimulus is that the nonreward trials are effectively punishers. For human subjects, the nonfeedback trials might function as aversive events because in everyday experience, wrong answers or other kinds of wrong responses often receive no feedback. For example, if an answer to a question is greeted by silence, the implication often is that the answer is incorrect. The bias effects found in the studies with humans when relative frequency of reinforcement is held constant and SPP is varied could be due to subjects' receiving far more nonreward trials for the stimulus presented most often and therefore receiving more punishment for reporting the occurrence of that stimulus. Consequently, responses become biased away from reporting the most frequently presented stimulus.

Experiment 1 also examined indirectly whether the lack of feedback following responses could serve as punishers for the responding of human subjects. In three additional conditions, subjects again received equal numbers of reinforcers on each key, and SPP was varied across conditions. However, subjects also received equal numbers of occasional events that might be expected to function as punishers for the two types of incorrect responses (losing 5 cents). Therefore, in these conditions the nonfeedback trials indicated not only an absence of reinforcement but also an absence of punishment. The additional background of punishers might make the nonfeedback trials, by comparison, more neutral, and human subjects might now show no systematic bias toward the response that indicates the occurrence of the least frequently presented stimulus.

## METHOD

### *Subjects*

Three male and 3 female undergraduate psychology students participated (15377, 23776, 211075, 26177, 24975, and 18772). Their ages ranged from 18 to 23 years.

### *Apparatus*

The experiment was conducted in the corner of a quiet, dimly lit room. A gray curtain was drawn around the subject to form an experimental area of 1 m by 2 m. This minimized visual distractions. The subject was seated directly in front of a computer with his or her head approximately 1 m from the screen. A bar at chest height prevented the subject from leaning closer to the computer.

A 486DX IBM®-compatible computer presented the signal-detection task and recorded the subjects' responses. Stimuli and instructions were displayed on a color monitor (640 by 480 pixels). The stimuli in this experiment were similar to the array stimuli used in experiments by Honig and Stewart (1989) and Honig (1991) in which subjects were required to make relative numerosity judgments. Stimuli consisted of  $12 \times 12$  arrays (measuring 71 mm by 71 mm); each element of the array was occupied by a circle or a square. The diameter of each circle and the width of each square measured 5 mm. The circles were filled and appeared white, whereas only a white outline defined the square. There was a gap of 1 mm between array elements. The stimuli classified as "more squares" had 74 random positions in the array occupied by squares, and the remaining 70 positions were occupied by circles. For the stimuli classified as "more circles," these proportions were reversed. Figure 3 gives an illustrative example of a more squares stimulus.

The subject responded on a two-key response panel (with telegraph keys) connected through the games port of the computer. The left key was marked with the words "more squares," and the right key was marked as "more circles."

### *Procedure*

Each subject participated in six experimental sessions, and the time between sessions was at least 24 hr but no more than 60 hr.

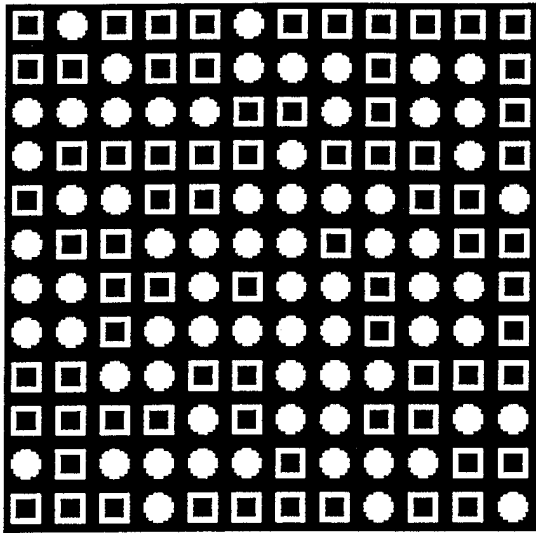


Fig. 3. An example of the more squares stimulus array.

Each session lasted for approximately 35 min and consisted of 500 trials preceded by a set of instructions. The subject was given an information sheet that included a simple description of the experiment, the payment conditions for participation, and an informed consent declaration. On the three experimental Sessions A1, A2, and A3, the following instructions were then presented.

You will see PATTERNS with either more squares [an example array showing more squares was presented] or more circles [an example array showing more circles was presented].

You will only see ONE pattern at a time.

If there are more SQUARES, press the LEFT button. If there are more CIRCLES press the RIGHT button.

Each pattern appears for 2 seconds. A small + precedes each trial—Like this [The small cross was then presented in the center of the screen, followed by the presentation of a more squares array].

That pattern had more squares so press the LEFT key.

Sometimes you are told you are correct and you win 5 cents. This looks like—[The words “correct” and “You win 5 cents!” were then displayed in the center of the screen against a colored pattern of pixel stars and a brief presentation of a 1000-Hz tone].

Sometimes you are told nothing. You could be right or wrong.

Get as much money as possible. You will be paid your total winnings at the conclusion of the experiment. You start with one dollar.

[The final instruction screen was then presented.]

Are you ready to begin the experiment? Remember: Press the left key if there are more squares, and right key if there are more circles.

Press any key to begin.

The experimental trials then began. Each trial began with a yellow cross presented in the middle of the screen for 750 ms. This served as a fixation point and a warning signal. An array stimulus containing either more circles or more squares then appeared and remained on the screen until the subject responded, or for a maximum of 2 s. If no response was made within the 2-s period, the screen remained blank until the subject made a choice. Each experimental session was divided into five blocks of 100 trials. At the end of each block, the subject's cumulative winnings were calculated; that is, the total amount of money earned for correct more circles and more squares choices was added and displayed on the screen. Pressing any key began the next block, allowing the subject to take a small break if desired.

The computer controlled the presentation probability of the more squares or more circles stimulus on each trial. The equal payoff distribution was achieved using a controlled reinforcer procedure (McCarthy & Davison, 1979; Stubbs & Pliskoff, 1969). The computer randomly selected the next correct response to be reinforced (more circles or more squares). This selection was constrained so that the reinforcer distribution that the subject obtained would be very similar to that arranged. Once the available reinforcer had been received, the computer selected the next correct response to be reinforced. This meant that each reinforcer had to be obtained before the subsequent reinforcer was arranged. Thus, the only time correct responses were not reinforced was when the computer had arranged a reinforcer for the opposite key. The maximum number of consecutive reinforcers available on the same key was constrained to eight. On nonreinforced but correct trials and on incorrect trials, no direct feedback was given. On these occasions, the screen remained blank for 1,250 ms

after the subject had responded and the next trial then began.

For Condition A1, the more squares and more circles stimuli were presented equally often (i.e., SPP = .5). For Condition A2, the probability of a more squares presentation was .2. For Condition A3, the probability of a more squares presentation was .8. Subjects received equal numbers of reinforcers (winning 5 cents) for correct more circles and correct more squares responses in all three conditions. Incorrect and nonreinforced responses produced the same consequences. On these trials the screen remained blank for 1,250 ms after the subject responded.

For the remaining three experimental conditions, there was one major procedural difference from Conditions A1, A2, and A3. In Conditions B1, B2, and B3, subjects also received occasional consequences that were intended to be punishers (losing 5 cents) for incorrect more circles and more squares responses, in addition to the equal reinforcer distribution. The equal distribution of the 5-cent losses across the alternatives was also arranged using a controlled procedure. Here, the computer arranged a punisher for an incorrect response on one key and only after subjects had received that particular punisher was the next one arranged. Thus, the only nonpunished incorrect trials occurred when there was a punisher arranged for an incorrect response on the opposite key. The maximum number of consecutive punishers received on one key was constrained to four.

Consequently, the instructions at the beginning of the experiment were altered to include a description of the consequences for incorrect trials. These instructions were inserted after the description of the consequences for correct trials and read as follows: "Sometimes you are told you are incorrect and you lose 5 cents. This looks like—" (The words "wrong" and "You lose 5 cents" were displayed against a black screen, and a 80-Hz tone was presented). In all other respects, the procedure for Conditions B1, B2, and B3 was the same as that for Conditions A1, A2, and A3. Subjects again received equal numbers of reinforcers for correct more circles and correct more squares responses, and the presentation probability of the more squares and more circles stimuli for Conditions B1, B2, and B3 matched the presentation probability

for Conditions A1, A2, and A3 (SPP of .5, .2, and .8, respectively). It was expected that subjects would earn between 5 and 10 dollars for each of the six experimental conditions, depending on their performance.

The order in which the six conditions were presented was partially counterbalanced across the 6 subjects, with the constraint that all three conditions from one group of conditions (A or B) were run consecutively. Table 1 details the exact presentation order for each subject.

## RESULTS AND DISCUSSION

The last three blocks (300 trials) from each experimental session (A1, A2, A3, B1, B2, and B3) were analyzed separately for each subject. The first 200 trials of each session were discarded because subjects would have had insufficient contact with the reinforcer distribution to reach a stable pattern of performance during these trials. The total number of more squares and more circles responses following  $S_1$  presentations ( $B_w$ ,  $B_x$ ) and  $S_2$  presentations ( $B_y$ ,  $B_z$ ) were calculated. The total number of reinforcers (winning 5 cents) obtained for correct responses on each key ( $R_w$  and  $R_x$ ) and the total number of punishers (losing 5 cents) obtained on each key ( $P_x$  and  $P_y$ ) were also calculated. Discriminability ( $\log d$ , Equation 1) and bias ( $\log b$ , Equation 2) measures were derived from these data. These values are given in Table 1.

Figure 4 plots the obtained  $\log d$  and  $\log b$  measures for each subject, when subjects received reinforcement only, across the varying SPP levels (Conditions A1, A2, and A3). Discriminability between the sample stimuli did not vary systematically across conditions. Response bias, however, varied systematically across changes in SPP. A statistically significant negative relation between  $\log (S_1/S_2)$  and  $\log b$  was obtained by fitting a least squares regression line to the data in Figure 4 (lower panel, slope =  $-0.26$ ,  $p < .05$ ). Not only was there a progressive change in the mean bias values over SPP Conditions .2, .5, and .8 (mean bias = 0.07,  $-0.13$ , and  $-0.27$ , respectively), but this change was monotonic for each subject. Thus, responding was systematically biased toward the key associated with the stimulus presented least often. For example, when  $S_1$  was presented on fewer trials than  $S_2$  (negative  $\log S_1/S_2$  values), mean

Table 1

The number of  $B_w$ ,  $B_x$ ,  $B_y$ , and  $B_z$  responses,  $R_w$  and  $R_z$  (reinforcers for correct responses), and  $P_x$  and  $P_y$  (punishers for incorrect responses) are given for individual subjects in each experimental condition. Discriminability measures ( $\log d$ ) and bias measures ( $\log b$ ) have also been calculated for each condition.

Subject	Condi- tion	$B_w$	$B_x$	$B_y$	$B_z$	$R_w$	$R_z$	$P_x$	$P_y$	$\log d$	$\log b$
15377	A1	101	49	48	102	55	56	0	0	0.32	-0.01
	A2	46	14	105	134	38	41	0	0	0.31	0.21
	A3	128	112	18	42	36	35	0	0	0.21	-0.16
	B1	91	59	45	105	52	51	30	30	0.28	-0.10
	B2	49	11	104	136	38	39	10	9	0.38	0.27
26177	B3	186	46	33	26	25	26	25	21	0.25	0.35
	B1	90	55	54	92	49	53	29	31	0.22	-0.01
	B2	49	9	81	151	41	44	7	8	0.50	0.23
	B3	106	122	18	41	27	32	15	15	0.15	-0.21
	A1	87	55	44	103	51	57	0	0	0.28	-0.09
211075	A2	39	21	98	139	37	37	0	0	0.21	0.06
	A3	119	109	18	38	36	34	0	0	0.18	-0.14
	A3	100	129	20	39	33	34	0	0	0.09	-0.20
	A2	45	12	84	149	38	42	0	0	0.41	0.16
	A1	84	64	38	111	54	53	0	0	0.29	-0.17
18772	B3	108	132	12	46	34	34	12	12	0.25	-0.34
	B2	33	27	76	163	30	28	24	23	0.21	-0.12
	B1	77	70	23	127	53	55	20	22	0.39	-0.35
	B3	171	62	21	38	35	34	17	17	0.35	0.09
	B2	51	9	132	98	35	34	10	9	0.31	0.44
23776	B1	73	68	44	98	41	40	31	31	0.19	-0.16
	A3	110	120	13	45	31	35	0	0	0.25	-0.29
	A2	29	19	67	145	26	31	0	0	0.26	-0.08
	A1	74	75	28	120	53	55	0	0	0.31	-0.32
	A2	40	19	110	121	32	34	0	0	0.18	0.14
24975	A3	105	124	10	48	37	37	0	0	0.30	-0.38
	A1	77	64	40	103	52	56	0	0	0.25	-0.17
	B2	48	12	136	101	34	35	8	11	0.24	0.37
	B3	140	99	16	44	38	36	15	16	0.29	-0.14
	B1	72	70	29	120	49	54	25	25	0.31	-0.30
	B2	46	12	120	118	38	40	9	11	0.29	0.30
	B3	141	87	22	36	33	35	20	19	0.21	0.00
	B1	84	53	57	82	47	44	28	29	0.18	0.02
	A2	39	21	72	167	34	34	0	0	0.32	-0.05
	A3	133	106	10	50	38	42	0	0	0.40	-0.30
	A1	97	52	49	100	61	59	0	0	0.29	-0.02

response bias was positive, indicating that subjects were biased towards making  $B_1$  responses.

Experiment 1 demonstrated that responding was biased toward reporting the least frequently presented stimulus even when a monetary reinforcer was used instead of a point reinforcer (as in Alsop et al., 1995). Thus, the use of what should have been a more highly valued reinforcer (money) did not eliminate the different pattern of response bias shown by each species when relative frequency of reinforcement was held constant and SPP was varied.

Figure 5 plots the obtained  $\log d$  and  $\log b$

measures for each subject when they received both reinforcers and monetary loss (intended as punishers) over the varying SPP levels (Conditions B1, B2, and B3). There were no systematic changes in discriminability ( $\log d$ ) across conditions. The lower panel indicates that subjects' response bias differed over SPP conditions. A least squares regression line fitted to the data in Figure 5 indicated that there was a significant negative relation between  $\log (S_1/S_2)$  and bias (slope =  $-0.23$ ,  $p < .05$ ). However, compared to Figure 4, Figure 5 provides less evidence that this relationship was a monotonic function, and there was greater variability in the response bias be-



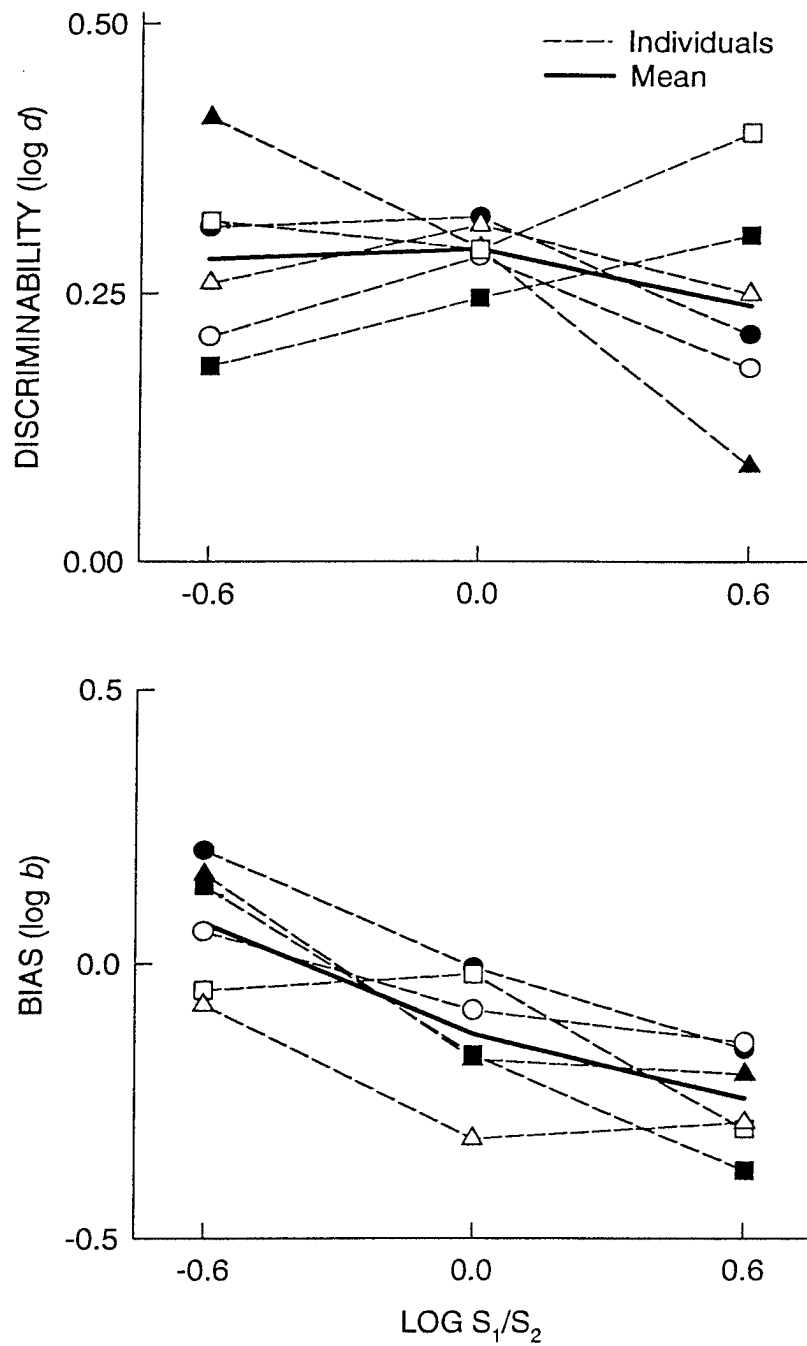


Fig. 4. The top panel shows discriminability ( $\log d$ , Equation 1), and the lower panel shows response bias ( $\log b$ , Equation 2) over changes in the log SPP ( $\log S_1/S_2$ ). Subjects received no direct feedback for incorrect trials. Both individual-subject data and the overall mean are given.

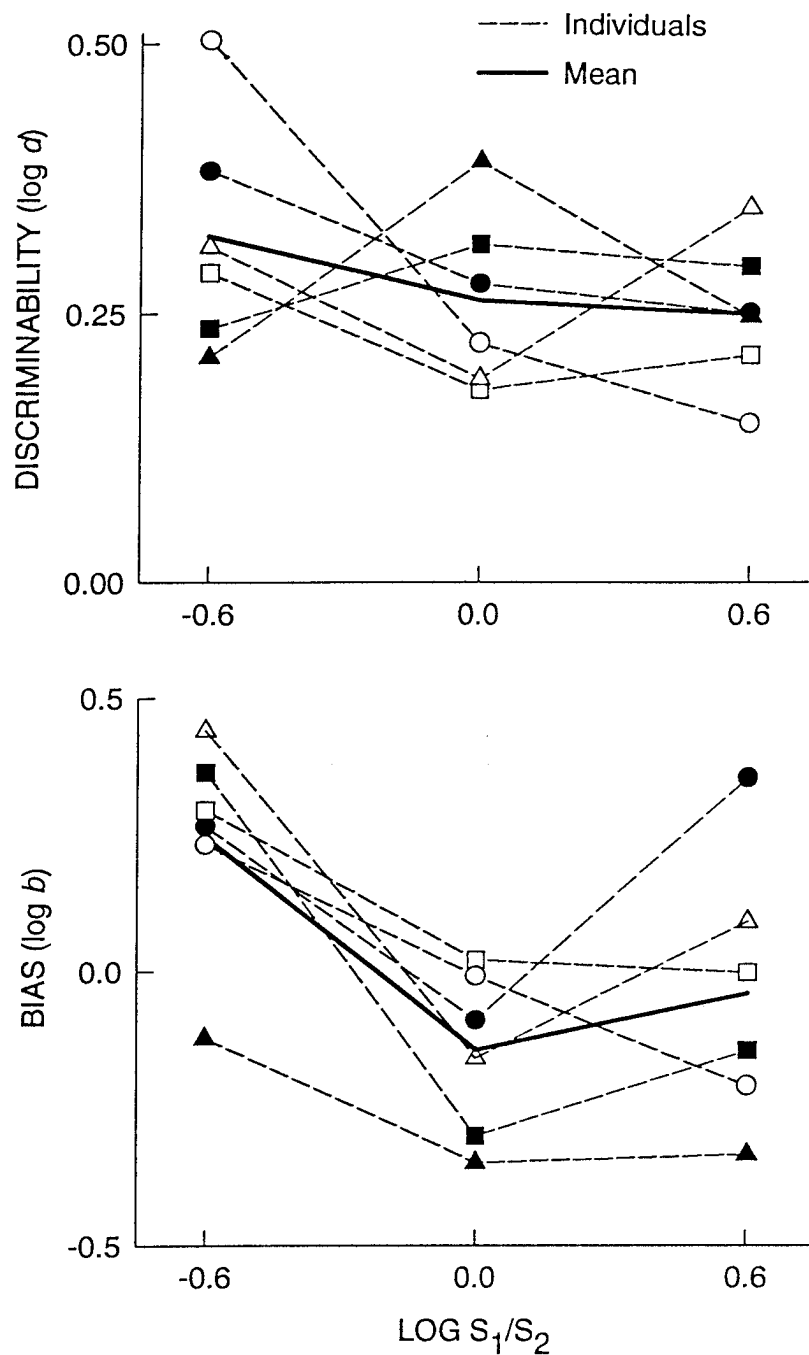


Fig. 5. The top panel shows discriminability ( $\log d$ , Equation 1), and the lower panel shows response bias ( $\log b$ , Equation 2) over changes in the log SPP ( $\log S_1/S_2$ ). Subjects received feedback on some incorrect trials. Both individual-subject data and the overall mean are given.

tween subjects. When SPP was varied from .2 to .5, all subjects showed a decrease in response bias (mean  $\log b = 0.24$  and  $-0.14$ , respectively). However, when SPP changed from .5 to .8, only 1 subject's response bias continued to decrease (SPP .8 mean  $\log b = -0.04$ ). This is in contrast to the data in Figure 4 that indicate that response bias consistently decreased when SPP changed from .5 to .8.

Adding a point-loss contingency to the signal-detection procedure disrupted subjects' performance (indicated by an increase in variability and a less obvious monotonic trend), but the pattern of response bias did not demonstrate clearly that the point loss consistently changed the value of the nonreinforced trials. This issue will be further examined in Experiment 3. Experiment 2 focuses on an additional procedural difference between McCarthy and Davison's (1979) and Alsop et al.'s (1995) studies: the consequences arranged for nonreinforced but correct responses.

## EXPERIMENT 2

In McCarthy and Davison's (1979) study, reinforcement consisted of 3-s grain access paired with a 3-s presentation of the magazine light. Nonreinforced but correct responses were not followed by grain, but the magazine light was presented. As mentioned earlier, it is possible that the magazine light acted as a conditioned reinforcer for these correct responses, and this conditioned reinforcer covaried with SPP; that is, pigeons received more conditioned reinforcers for the stimuli presented most often. Alsop et al. (1995) and Experiment 1 of the current study arranged the same consequences for nonreinforced correct responses and incorrect responses when SPP was varied and relative frequency of reinforcement was held constant; that is, there was no direct feedback arranged for these two types of responses. This difference between the consequences for correct but nonreinforced responses and incorrect responses might have contributed to the discrepancy between the performances of humans and pigeons on this task.

Experiment 2 was a systematic replication of McCarthy and Davison's (1979) Procedure 2, in which SPP was varied and relative fre-

quency of reinforcement was held constant. The point was to investigate whether human subjects would perform like pigeons in this type of signal-detection task when the procedures used for each species were made more directly comparable. Correct responses in the present experiment resulted in two possible outcomes: the already-effective reinforcer (money) or a stimulus that had formerly been paired with the reinforcer.

## METHOD

### *Subjects and Apparatus*

One male and 5 female undergraduate psychology students participated (9373, 17667, 30773, 41273, 171170, and 20868). The subjects' ages ranged from 22 to 28 years. The apparatus was identical to that used in Experiment 1.

### *Procedure*

Subjects participated in three experimental conditions, and the time between each session was no less than 24 hr but no more than 60 hr. The general procedure for the three conditions (C1, C2, and C3) was similar to Conditions A1, A2, and A3, respectively, in Experiment 1, in which there was no direct feedback arranged for incorrect trials, and SPP was held at .5, .2, and .8, respectively. However, unlike Experiment 1, correct responses produced one of two possible consequences. First, if a reinforcer was arranged for that correct response, the consequences were the same as in Experiment 1 (5 cents, the word "correct," a pattern of pixel stars, and a 1000-Hz tone). Again, an equal number of primary reinforcers was arranged for correct left-key and right-key responses, as in Experiment 1. Second, if the subject made a correct response and there was no reinforcer scheduled for that response, the word "correct" appeared on the center of the screen, but the subject received no monetary reinforcement. Consequently, the instructions at the beginning of the experiment were expanded to inform subjects that on some trials they would be told they were correct but that they would receive no money. No reference was made to the consequences for incorrect trials.

The order in which the three conditions were presented was counterbalanced across

Table 2

The number of  $B_w$ ,  $B_x$ ,  $B_y$ , and  $B_z$  responses,  $R_w$  and  $R_z$  primary reinforcers, and  $r_w$  and  $r_z$  conditioned reinforcers are given for each subject in each condition. Discriminability ( $\log d$ ) and bias ( $\log b$ ) measures have also been calculated.

Subject	Condition	$B_w$	$B_x$	$B_y$	$B_z$	$R_w$	$R_z$	$r_w$	$r_z$	$\log d$	$\log b$
9373	0.2	25	35	36	204	22	23	3	181	0.30	-0.45
	0.5	95	55	59	91	42	43	53	48	0.21	0.02
	0.8	166	74	26	34	26	27	140	7	0.23	0.18
30773	0.5	104	45	61	88	46	43	58	45	0.26	0.10
	0.8	198	42	35	25	19	21	179	4	0.26	0.41
	0.2	27	31	75	160	20	19	7	141	0.13	-0.19
41273	0.8	196	44	39	21	12	14	184	7	0.19	0.46
	0.2	17	43	41	199	16	15	1	184	0.14	-0.54
	0.5	87	63	37	113	40	39	47	74	0.31	-0.17
20868	0.2	19	41	42	198	16	15	3	183	0.17	-0.50
	0.8	219	21	47	13	12	12	207	1	0.23	0.79
	0.5	103	47	65	85	39	40	64	45	0.23	0.11
17667	0.8	227	4	54	4	5	4	222	0	0.31	1.44
	0.5	113	37	55	95	45	44	68	51	0.36	0.12
	0.2	14	46	10	230	12	13	2	217	0.42	-0.94
171170	0.5	79	71	53	96	33	35	46	61	0.15	-0.11
	0.2	42	18	78	162	33	32	9	130	0.34	0.03
	0.8	170	70	30	30	24	25	146	5	0.19	0.19

subjects. Table 2 provides the presentation order for each subject.

#### RESULTS AND DISCUSSION

The last 300 trials from each experimental condition (C1, C2, and C3) were analyzed for each subject in the same manner as those from Conditions A1 to A3 of Experiment 1. These results are given in Table 2.

Figure 6 plots the obtained  $\log d$  and  $\log b$  for each subject in each session. A statistically significant positive relation between  $\log (S_1/S_2)$  and  $\log b$  was obtained by fitting a least squares regression line to the data in Figure 6 (lower panel; slope = 0.84,  $p < .05$ ). Subjects showed a systematic bias for the key associated with the stimulus presented most often; that is, the average bias was negative ( $M = -0.43$ ) when  $\log (S_1/S_2) = -0.6$ , and bias was positive ( $M = 0.57$ ) when  $\log (S_1/S_2) = 0.6$ . When  $\log (S_1/S_2) = 0$ , subjects showed no systematic preference for responding on either key ( $M = 0.01$ ). The positive relationship between SPP and response bias was the opposite of the negative relationship found in Experiment 1. In addition, this positive relationship was reliable across subjects, in that all showed monotonically increasing functions. Discriminability did not change system-

atically over the SPP conditions (mean  $\log d = 0.25$ , 0.25, and 0.24 for C1, C2, and C3, respectively).

Experiment 2 demonstrated that the consequences for correct responses that are not followed by a presentation of the monetary reinforcer are powerful determinants of subjects' response bias when SPP is varied and relative frequency of reinforcement is held constant. When there were no direct consequences for correct but nonreinforced responses, subjects showed a response bias toward reporting the stimulus that was presented least often (Experiment 1). However, when the feedback for the nonreinforced but correct responses changed from no direct feedback to feedback consisting of a likely conditioned reinforcer (Experiment 2), the opposite relation between SPP and response bias was found.

This finding might explain the difference between the response bias of humans and pigeons when SPP is varied and relative frequency of reinforcement is held constant. If the magazine light in McCarthy and Davison's (1979) study had some reinforcing effect, then the combined effects of the conditioned reinforcer and the primary reinforcer could result in no systematic

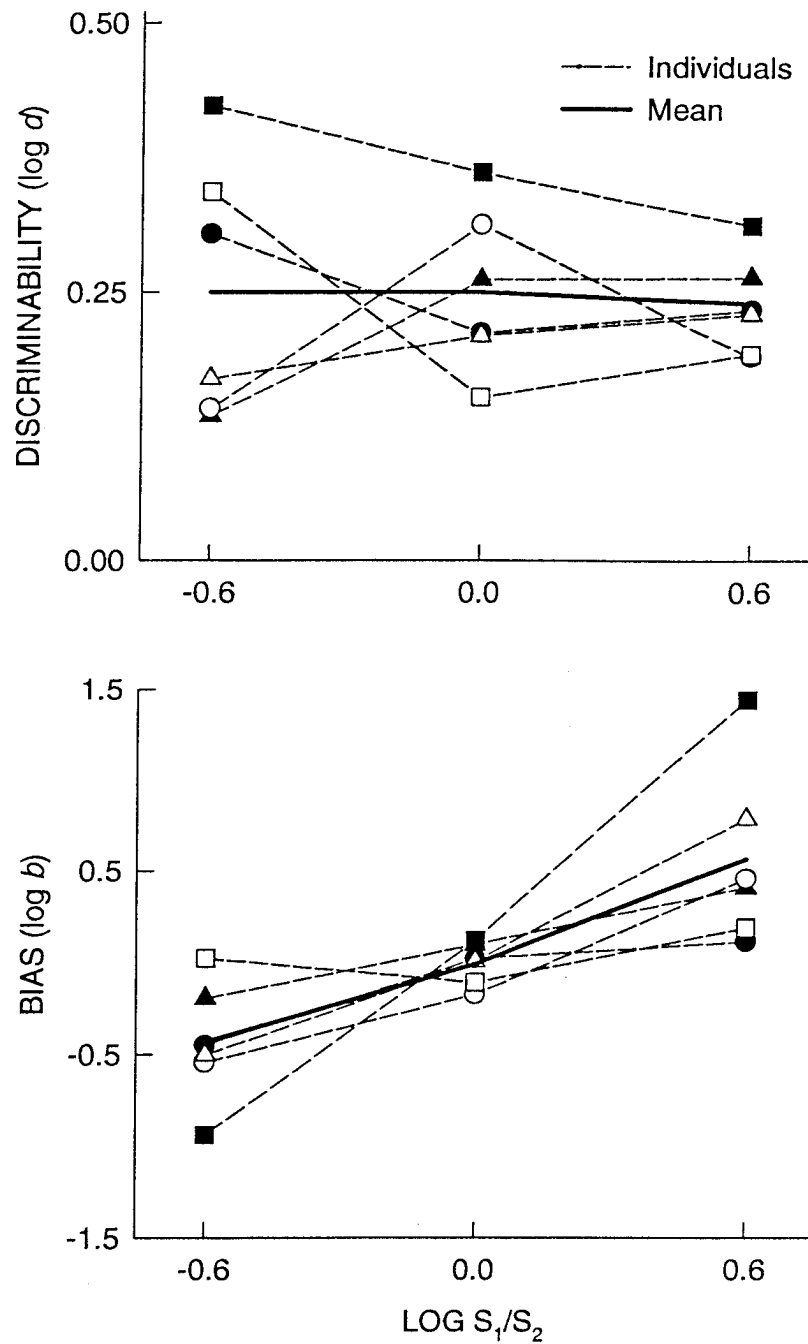


Fig. 6. The top panel shows discriminability ( $\log d$ , Equation 1), and the lower panel shows response bias ( $\log b$ , Equation 2) over changes in the log SPP ( $\log S_1/S_2$ ). Subjects received a conditioned reinforcer for nonreinforced but correct responses. Both individual-subject data and the overall mean are given.

change in response bias over the changing SPP levels for the pigeons. In the present study the word "correct" might have held a stronger reinforcing value than a magazine light for pigeons. If the total amount of reinforcement obtained on an alternative is the sum of the primary and conditioned reinforcers, then as the conditioned reinforcer is made more effective, preferences should become more extreme. Such an effect would result in the positive relationship between  $\log(S_1/S_2)$  and response bias as shown in Figure 6, compared to the flat function shown by the birds in Figure 2, when SPP is varied and the primary reinforcer distribution is held constant. It seems likely therefore, that a procedural difference between the human and pigeon studies, rather than a fundamental species difference, is responsible for the differences in performance between humans and pigeons when SPP is varied and relative frequency of reinforcement is held constant.

### EXPERIMENT 3

The data from Experiment 2 suggest that a general species difference might not be responsible for the differences found between humans and pigeons in how response bias changes when SPP is varied and relative frequency of reinforcement is held constant. The data also suggest that pigeons might respond similarly to how humans respond if the conditioned reinforcer is removed. It is still unclear, however, why the response bias for the stimulus presented least often occurs for humans. Experiment 3 investigated the hypothesis that humans were biased towards responding to the stimulus presented least often because they received fewer nonfeedback trials for these types of responses. This hypothesis makes specific predictions about how bias should change when the overall rate of reinforcement is varied. These predictions can be illustrated by examining a plausible model of the effects of punishment in choice procedures.

Baum and Rachlin (1969) proposed that behavior across two alternatives is allocated according to the ratio of the absolute reinforcing values associated with the two responses. Farley and Fantino (1978) specified this relation further by the following equation,

where  $V$  represents the reinforcing value.

$$\log\left(\frac{B_1}{B_2}\right) = \log\left(\frac{V_1}{V_2}\right). \quad (4)$$

The absolute reinforcing value correlated with each response can be described as the combination of reinforcers and punishers contingent on that response. Farley and Fantino found evidence that the effect of a punisher is to reduce the overall reinforcer potency on that key (e.g., Millenson & de Villiers, 1972). This relationship is described by the following equation,

$$\log\left(\frac{B_1}{B_2}\right) = \log\left(\frac{R_1 - cP_1}{R_2 - cP_2}\right), \quad (5)$$

where  $B$ ,  $R$ , and  $P$  represent the number of responses, reinforcers, and punishers, respectively, and  $c$  represents the effect of a punisher relative to that of the corresponding reinforcer. For example, if  $c$  equals 0.5, then one reinforcer is twice the value of one punisher (but is opposite in sign).

If the nonfeedback trials in the present study act as punishers, then Equation 5 makes a prediction concerning the effects of changing the overall reinforcer rate. If the relative number of reinforcers received for responding on each key is kept constant and the overall reinforcer rate is reduced, then the bias for reporting the stimulus that is presented least often should increase. The following experiment altered the overall amount of reinforcement available when SPP was varied and relative frequency of reinforcement was held constant and equal across each key. It was expected that subjects would be more biased toward reporting the stimulus that is presented least often when the overall amount of reinforcement available is reduced, as predicted by Farley and Fantino's (1978) model of punishment.

### METHOD

#### *Subjects*

Two male and 2 female undergraduate psychology students participated (15574, 7876, 29876, and 13675). The subjects' ages ranged from 18 to 21 years.

Table 3

The number of  $B_w$ ,  $B_x$ ,  $B_y$ , and  $B_z$  responses,  $R_w$  and  $R_z$  reinforcers, and the average number of trials per reinforcer (tr/rfr) are shown for each subject in each condition. Discriminability ( $\log d$ ) and bias ( $\log b$ ) measures have also been calculated.

Subject	Condition	$B_w$	$B_x$	$B_y$	$B_z$	$R_w$	$R_z$	tr/rfr	$\log b$	$\log d$
15574	R2	145	95	5	55	41	42	3.61	-0.43	0.61
	L1	53	4	76	161	26	25	5.76	0.40	0.72
	L2	151	89	10	50	22	23	6.67	-0.23	0.46
	R1	55	5	85	154	48	46	3.18	0.39	0.65
7876	L2	163	77	7	53	27	27	5.56	-0.28	0.60
	R1	53	7	89	151	40	42	3.67	0.32	0.55
	R2	184	56	3	57	48	50	3.06	-0.38	0.90
	L1	50	9	90	149	24	23	6.34	0.26	0.48
29876	R1	54	6	64	176	48	50	3.06	0.26	0.70
	L2	140	99	2	58	23	23	6.50	-0.66	0.81
	L1	53	6	82	158	25	24	6.10	0.33	0.62
	R2	139	99	4	54	36	40	3.90	-0.49	0.64
13675	L1	59	1	100	140	25	27	5.76	0.54	0.96
	R2	171	69	6	54	46	50	3.36	-0.28	0.67
	R1	58	2	105	135	46	45	3.30	0.48	0.79
	L2	148	92	9	51	26	25	5.88	-0.27	0.48

### Apparatus

The apparatus used was similar to that used in Experiment 1. The only difference was that the circle:square ratio in the array stimuli was altered. Here, a stimulus classified as more circles had 77 positions in the array occupied by circles and 67 positions occupied by squares. These proportions were reversed for the more squares stimuli. The increase in stimulus disparity from Experiments 1 and 2 was made to promote more correct responses and thus to allow more flexibility in varying the overall amount of reinforcement each subject could receive.

### Procedure

Subjects participated in four experimental conditions; each condition was separated by no less than 24 hr but no more than 60 hr. The general procedure for two conditions (R1 and R2) was identical to Conditions A2 and A3, respectively, in Experiment 1, in which there was no direct feedback for incorrect responses. SPP was held at .2 for Condition R1 and at .8 for Condition R2. Subjects again received equal numbers of reinforcers for each type of correct response (more circles and more squares).

For the remaining two conditions (L1 and L2, SPP = .2 and .8, respectively), the overall number of reinforcers available was reduced

by approximately half. Although the total number of reinforced responses was reduced, subjects still received equal numbers of reinforcers for responding on both keys. The order in which the four conditions were presented was partially counterbalanced across subjects (Table 3).

### RESULTS AND DISCUSSION

The last three blocks (300 trials) from each experimental condition were analyzed in the same manner as for Experiments 1 and 2. Furthermore, in the conditions in which subjects received a comparatively low reinforcement rate (L1 and L2), the average bias for reporting the least frequently presented stimulus ( $S_1$  for Condition L1 and  $S_2$  for Condition L2) was calculated. The average bias for reporting the least frequently presented stimulus was also calculated for the conditions that provided comparatively more reinforcers (R1 and R2). In addition, the average number of trials per reinforcer (a measure analogous to the inverse of rate of reinforcement) was calculated for each subject in each condition. These values are given in Table 3.

Subjects received approximately half the number of reinforcers in Conditions L1 and L2 (average number of trials per reinforcer = 6.1) compared to Conditions R1 and R2 (average number of trials per reinforcer =

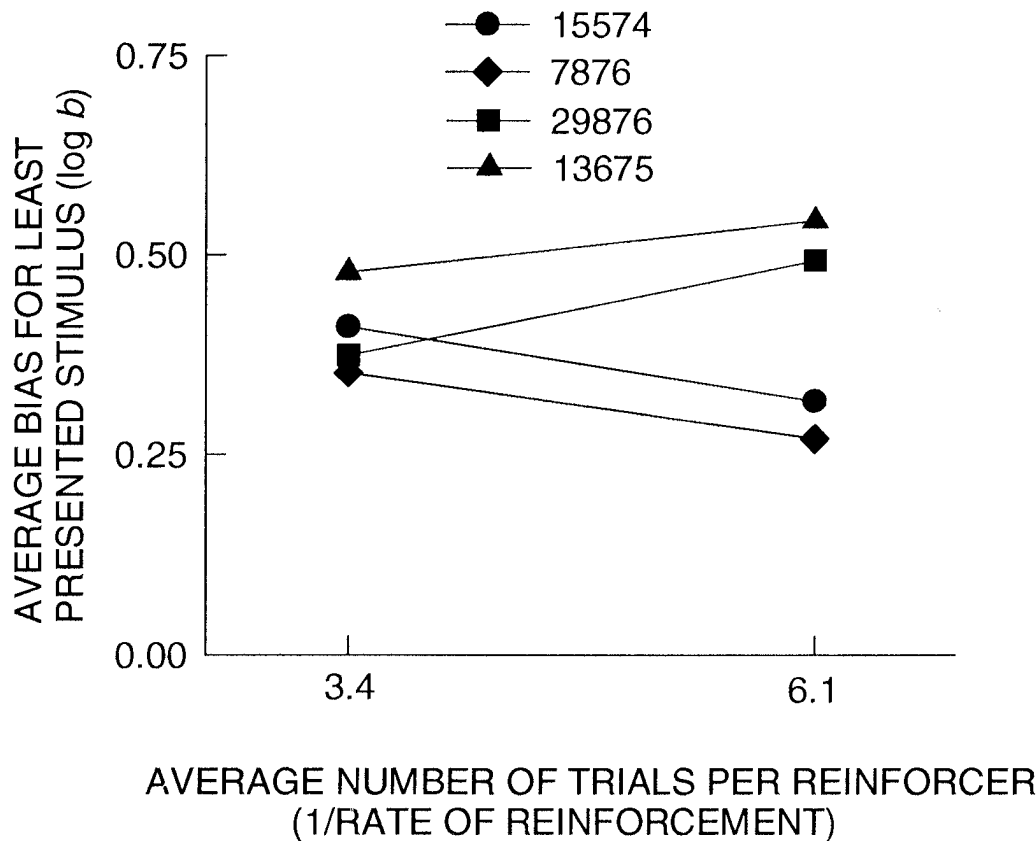


Fig. 7. Individual subjects' mean bias toward the stimulus presented least often plotted against the lean reinforcement rate (6.1 trials per reinforcer) and the rich reinforcement rate (3.4 trials per reinforcer).

3.4). Discriminability did not change systematically over the four conditions (mean  $\log d$  for L1 = 0.70, L2 = 0.59, R1 = 0.67, and R2 = 0.70).

There was no systematic change in subjects' response bias across conditions with lean and rich rates of reinforcement. Figure 7 plots the average bias for reporting the least frequently presented stimulus for each subject across the low and high rates of reinforcement. Response bias increased for Subjects 15574 and 7876 and decreased for Subjects 29876 and 13675 as the reinforcer rate increased. Furthermore, the extent of these changes was relatively small, and the absolute values of  $\log b$  for each subject were quite similar. Therefore, changes in the overall reinforcement rate produced no systematic change in response bias when SPP was varied and relative frequency of reinforcement was held constant. Thus, the data provided no evidence

that an account based on Farley and Fantino's (1978) model of punishment explains the response bias in humans for the least frequently presented stimulus. It must be noted, however, that the change in the overall reinforcement rate between the lean and rich conditions was not particularly large. It is possible that the number of nonreinforced responses in the low-reinforcer-rate conditions was insufficient to produce a more extreme response bias than that in the rich-reinforcer-rate conditions.

#### EXPERIMENT 4

Experiment 4 investigated whether differences in the amount of training given to humans (Alsop et al., 1995) and pigeons (McCarthy & Davison, 1979) contributed to the different patterns of response bias. If response bias of humans toward reporting the



least frequently presented stimulus was a transient effect, then humans should show less bias with extended training. Subjects in Experiment 4 were trained over 2,000 trials with an SPP of either .2 or .8 and a constant and equal reinforcement rate. This level of training represented a fourfold increase over that given in Experiments 1 to 3. Although McCarthy and Davison's birds received even more training, most of their birds received more trials than necessary to reach stability because all birds had to meet the stability criterion before a condition was changed. Furthermore, if the human subjects' response bias was transient, then at least some ordinal changes should be evident by 2,000 trials.

#### METHOD

##### *Subjects and Apparatus*

Two male and 2 female undergraduate psychology students participated (24675, 30876, 21277, and 11577). The subjects' ages ranged from 18 to 20 years. The apparatus used was identical to that used in Experiment 1.

##### *Procedure*

Each subject participated in four experimental sessions, and the time between sessions was at least 24 hr but no more than 60 hr. The general procedure for Subjects 24675 and 30876 was identical to Condition A1 in Experiment 1, and the probability of a more squares presentation was held at .2 (i.e., SPP = .2) for all four experimental sessions. For the remaining 2 subjects, the general procedure was identical to Condition A3 in Experiment 1, and the probability of a more squares presentation was .8 (i.e., SPP = .8) for all four experimental sessions.

#### RESULTS AND DISCUSSION

The last three blocks (300 trials) from each experimental session were analyzed separately for each subject. The total number of  $B_w$ ,  $B_x$ ,  $B_y$ , and  $B_z$  responses,  $R_w$  and  $R_z$  reinforcers, and measures of discriminability ( $\log d$ ) and bias ( $\log b$ ) were calculated for each subject in each of the four sessions.

Over successive sessions, discriminability tended to increase (means of 0.12, 0.19, 0.23, and 0.26). A statistically significant linear trend in discriminability was found across the training sessions,  $F(1, 9) = 5.73$ ,  $p < .05$ . Figure 8 plots the obtained  $\log b$  values for each

subject for each session. Here, response bias was plotted for the stimulus presented least often ( $S_1$  for Subjects 24675 and 30876 and  $S_2$  for Subjects 21277 and 11577). If bias for reporting the least frequently presented stimulus was a transient feature of human performance on this task, response bias should have decreased as training continued. Subjects' response bias, however, did not systematically decrease over successive sessions and, if anything, increased slightly (Session 1 = 0.08, Session 2 = 0.12, Session 3 = 0.14, and Session 4 = 0.14). There is no evidence that the humans' response bias for the key associated with the stimulus presented least often was a transient effect. Therefore, the difference between the performance of pigeons and humans on this task does not appear to be a function of the amount of training associated with each species.

#### GENERAL DISCUSSION

The present experiments showed that Alsop et al.'s (1995) findings are robust and reliable. The responses of human subjects were biased towards the key associated with the stimulus presented least often when the reinforcement distribution was held equal and constant. Furthermore, this result was reliable even with extended training (Experiment 4) and with a different type of reinforcer (Experiments 1, 3, and 4). This reliability was important because the results of Alsop et al. conflict with corresponding pigeon data (McCarthy & Davison, 1979), with the behavioral signal-detection view that SPP manipulations alone do not produce systematic changes in response bias (McCarthy & Davison, 1979, 1981), and with the traditional signal-detection view that SPP manipulations result in response bias for the key associated with the stimulus presented most often (e.g., Pang, Merkel, Egeth, & Olton, 1992).

The present experiments also show that the use of probable conditioned reinforcers in the McCarthy and Davison (1979) study might have contributed to the differences in response bias found between pigeons and humans. When conditioned reinforcers were given for otherwise nonreinforced correct responses, human subjects no longer showed response bias for the key associated with the stimulus presented least often (Experiment

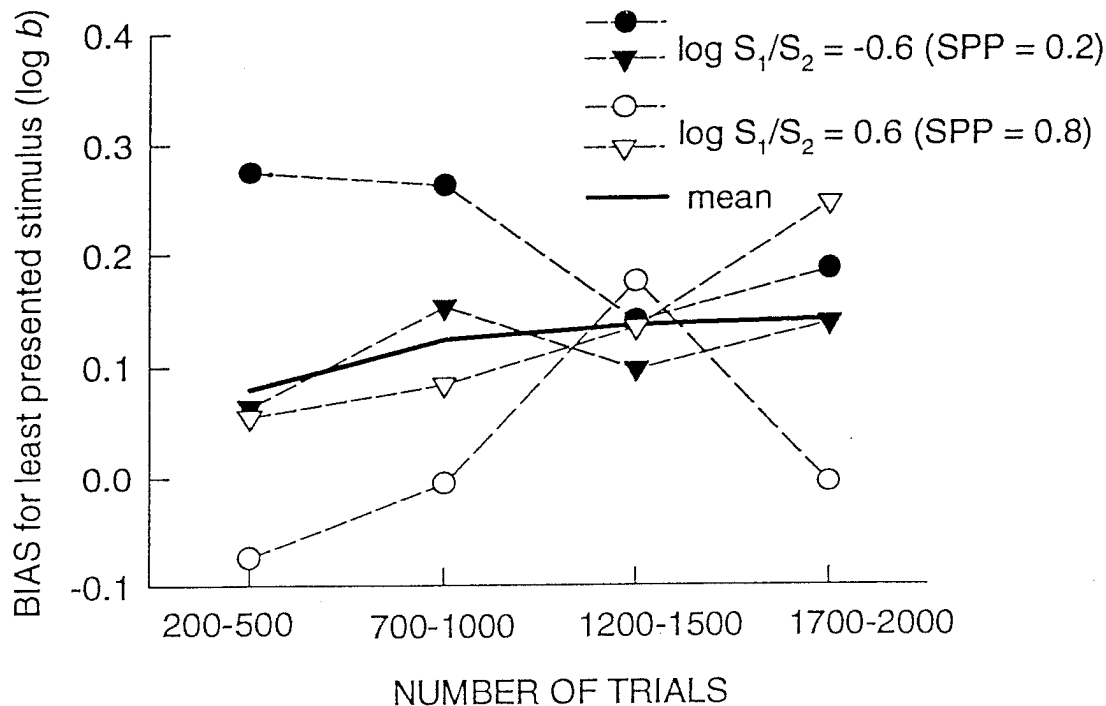


Fig. 8. Response bias ( $\log b$ , Equation 2) for each subject is plotted over successive numbers of trials. The overall mean bias values are also given.

2). Instead, their responses were biased towards the key associated with the stimulus presented most often. McCarthy and Davison used a procedure comparable to that of Experiment 2; that is, a conditioned reinforcer was presented for nonreinforced but correct responses. Therefore, a procedural difference in the consequences for nonreinforced correct responses seems to be the most likely reason why pigeons and humans performed differently when SPP was varied and relative frequency of reinforcement was held constant. If the conditioned reinforcer were removed for nonreinforced correct responses with pigeons, would they perform like the human subjects when SPP is varied and relative frequency of reinforcement is held constant? This result seems likely, given the results of the current study. Regardless, removing the conditioned reinforcers would provide a more accurate account of SPP effects on bias in pigeons, because the effective reinforcer distribution would be more like the arranged distribution.

If the presentation of a magazine light served as a conditioned reinforcer with pi-

geons, the results from some previous studies might need to be reconsidered. The use of the magazine light to signal correct but nonreinforced responses has been a common procedural arrangement (e.g., McCarthy, 1983; McCarthy & Davison, 1979, 1980a, 1980b, 1982, 1984). For example, McCarthy and Davison (1982) demonstrated that discriminability was independent of absolute rate of reinforcement. Although they varied the overall rate of the primary reinforcer, all correct responses produced the presentation of a magazine light. Therefore, the overall rates of reinforcement might not have varied to the extent intended, and any changes in discriminability might have been too small to detect reliably. McCarthy and Davison (1982) provided some evidence that discriminability remained constant whether correct nonreinforced and incorrect responses received the same feedback (both produced blackout) or differential feedback (nonreinforced correct responses lit the magazine light and incorrect responses produced blackout). However, these results were from 2 subjects only, and the conditions were run at the end of the study after extensive

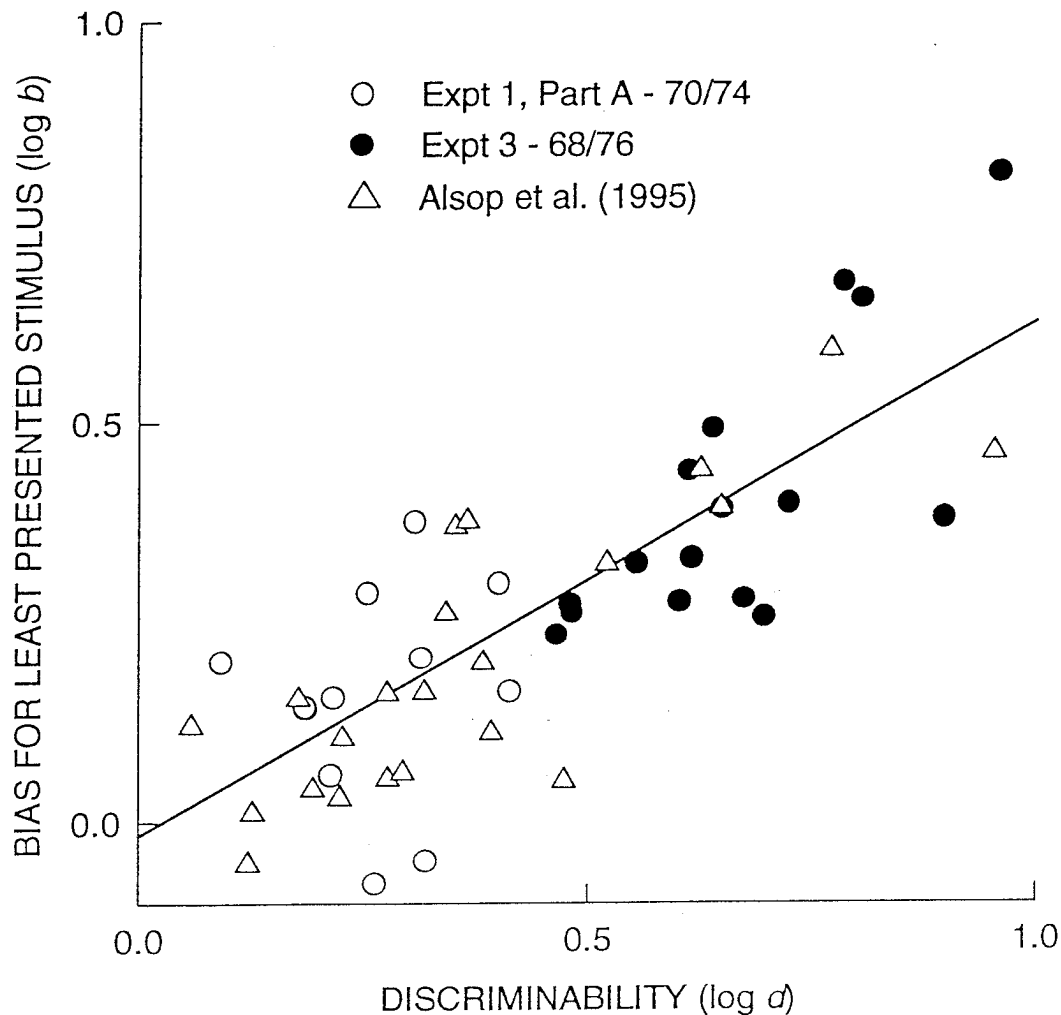


Fig. 9. Bias for the least frequently presented stimulus plotted against the corresponding discriminability measure. Data are from Experiment 1, Part A, Experiment 3, and Alsop et al. (1995). Circle:square ratios for the stimulus array are given for Experiment 1, Part A (hard discriminability), and Experiment 3 (easier discriminability).

training. Furthermore, a reanalysis of this study by Alsop et al. (1995) suggests that there were differences in response bias across these two procedures. It appears that a reexamination of the effects of arranging differential consequences for correct nonreinforced and incorrect responses is in order, especially given this procedure's pervasiveness in studies of signal detection in nonhumans.

Given that Alsop et al.'s (1995) findings are robust, the question remains as to why SPP manipulations of this sort produce bias for the key associated with the stimulus presented least often. Alsop et al. considered two possible mechanisms to explain this result.

First, they proposed that subjects perceive all nonreinforced trials negatively and thus show a bias because they receive more of these types of trials for the stimulus presented most often. The data from the current experiments provided little support for this possibility. Response bias should have decreased when the overall amount of reinforcement was increased, but it did not (Experiment 3). However, this possibility cannot be ruled out, because the difference in the overall reinforcement rate between the lean and rich conditions of Experiment 3 was not varied over a particularly wide range (from approximately 3.5 to 6 trials per reinforcement).

The second mechanism considered by Alsop et al. (1995) is that responding by humans might be influenced by the conditional reinforcement probabilities on each key rather than the overall reinforcement distribution. By this account, humans are biased toward reporting the stimulus that is presented least often because they receive proportionally more reinforcers per total number of responses for that response; in other words, responding by the human subjects was biased because their behavior approximated an attempt to equalize the conditional probabilities of reinforcement. A conditional probability explanation is consistent with the results from Experiment 3. When the overall amount of reinforcement was altered, the conditional probability of a reinforcer on each key remained equal, and subjects showed no systematic change in response bias. The conditional probability account is, however, inconsistent with some of the results from Alsop et al., in that marked changes in response bias occurred under conditions in which a conditional probability explanation predicts no change.

The present set of experiments offers some directions for future investigations into the factors that produce bias for the key associated with the least frequently presented stimulus. In particular, it appears that the extent of response bias was a function of stimulus discriminability. Figure 9 plots bias values against the corresponding discriminability values for Experiment 1 (Part A) and Experiment 3. As discriminability increased, bias for reporting the least frequently presented stimulus became more extreme. This finding is consistent with data from Alsop et al. (1995), also plotted in Figure 9. Although the relationship between discriminability and response bias can serve to preclude some factors that account for the response bias effect, it cannot separate an explanation based on the negative effect due to nonreinforced responses from a conditional probability account. With an increase in discriminability, subjects make more correct responses and thus receive more nonreinforcement trials for reporting the stimulus that is presented most often. If these consequences are punishers, they should produce more extreme bias for the key associated with the stimulus presented least often. Similarly, if subjects are at-

tempting to match the conditional probability of reinforcement on each key, an increase in nonreinforced correct responses will decrease the conditional probability of reinforcement on that key and result in bias for the other alternative.

The results of the present experiments and those of Alsop et al. (1995) challenge important assumptions of both traditional models and behavioral models of signal detection. The effect of SPP on human response bias is not what established views of signal detection would have us expect, and the present experiments also indicate that this finding probably extends to other species. If the goal of signal-detection models is to predict and measure behavior accurately in signal-detection tasks, factors that influence discriminability and bias need to be well understood.

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